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Stand characteristics and *Ips typographus* (L.) (Col., Curculionidae, Scolytinae) infestation during outbreak in northeastern Poland

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Abstract

The study included field data collected from outbreak areas of Norway spruce beetle *Ips typographus* L., which were used to identify stand conditions associated with outbreak populations. In 2001–2002 data from 100 infested and 100 uninfested plots were collected from eight Forest Districts of State Forests and three National Parks in northeastern Poland. Among 17 analyzed variables only the number of trees for all species resulted in a significant difference between infested and uninfested stands. To develop probability of infestation models, a statistical technique called Classification and Regression Trees (CART) was used. Results of classification models indicate increased probability of infestation when stand density index for all species of trees present declines below 14.1 per plot (0.02 ha) (about 0.6 of common density index used in polish forestry) and for stands with a high percentage of spruce (> 92.2 percent).

Key words

Ips typographus outbreak, stand characteristics

Introduction

The Norway spruce beetle *Ips typographus* L., is a major disturbance agent associated with Norway spruce, *Picea abies* Karst. in Poland. Thousands of cubic meters of infested wood are removed from forested areas annually. Sanitation practices are considered to be the most effective method of limiting *I. typographus* activity (Wermelinger, 2004). Often a large number of infested and susceptible down, damaged, and standing trees are salvaged during ongoing outbreaks of the bark beetle. Outbreaks are usually initiated by various disturbances like windthrow, severe drought, or serious weakening of the trees caused by pathogenic fungi (Lieutier, 2004). Such trees attract beetles by releasing host volatiles (Lindelow *et al.*, 1992). Norway spruce beetle outbreaks occur periodically in northeastern Poland every several years (Hilszczański and Kolk, 2001) when forest patches infested by *I. typographus* are commonly observed within a matrix of spruce and mixed stands.

The principle objective of this research was to develop a Norway spruce beetle susceptibility-rating system that would be applicable to forest areas in northeastern Poland. It was found that several site and stand factors are associated with characteristics that increase a tree's susceptibility to bark beetle attack: tree age, exposition, bark anatomy, altitude, soil nutrients, water supply, etc. (Lieutier, 2004; Lobinger et Skatulla, 1996; Jakuš, 1998; Dutilleul *et al.*, 2000; Lexer, 1997). Stand characteristics that can be manipulated using silvicultural treatments to reduce the susceptibility of spruce to bark beetle attacks are of interest to the forest management community (Negron, 1998; Wermelinger, 2004). Characteristics that can be vegetatively manipulated include: age class diversity, stand density, proportion of spruce and species composition. To develop guidelines for managers it is very important to understand how those characteristics are related to probability of *Ips* infestation.

In this experiment, data was collected from 100 plots infested by *I. typographus* and 100 uninfested plots. Research objectives associated with this study were:

- Are there any differences in stand characteristics between infested and uninfested plots that affect stand susceptibility to this insect?
- Are specific stand characteristics quantifiable to develop probability of infestation and stand susceptibility model?

Research Design and Methodology

The geographic area of the study was limited to northeastern Poland because of the similarity in forest conditions found throughout this area.

To develop models that estimate the probability of infestation by bark beetles, 100 plots (0.02 ha, 7.98 m radius) were established in current or previously infested sites and 100 plots (75 m in a random direction from the infested plot) in an uninfested site. Study plots were located away from the forest edge in the interior portion of the stand where populations of *I. typographus* are typically found. The center point for each infested plot was established randomly and often close to the initially infested tree within the polygon of dead and infested hosts.

The following data were collected for each plot:

- tree diameter and species for all trees greater than 7 cm diameter at breast height dbh,
- tree height,
- crown position (dominant, codominant, intermediate, suppressed)
- previous 12-year radial increment (one or two spruce trees per plot were sampled for all crown position classes except suppressed),
- tree status (live, beetle-killed, fungus-killed or dead from other causes).

With this information we calculated mean tree diameters, quadratic mean diameter, total height, basal area, stand density index and trees number per plot for all species and for spruce only. We also calculated percent of basal area in spruce, mean and total spruce radial growth for the last 12 years, periodic growth rates and mean height for all dominant and codominant spruce. Periodic growth rate was obtained by dividing the last 10 years growth by the 10 previous years. Stand density index was calculated using individual tree contribution to stand density as:

$$\Sigma\,(\mathrm{dbh}/25)^{1.6}\ \text{(Long and Daniel 1990).}$$

Stand density index is a measure of competition between trees in the stand and is a relationship between tree diameter and trees number per unit area (Long 1985; Long and Smith 1984).

All data were collected during the field seasons in 2001 and 2002. Field data for all plots occurred on the following Forest Districts of State Forests and National Parks in Poland: Krynki Forest District, Supraśl Forest District, Suwałki Forest District, Hajnówka Forest District, Browsk Forest District, Białowieża Forest District, Strzałowo Forest District, Czarna Białostocka Forest District and Białowieski National Park, Biebrzański National Park, Wigierski National Park.

A statistical technique called Classification and Regression Trees (CART) was used to develop probability of infestation models to determine tree and stand parameters associated with host susceptibility to Norway spruce beetle. This technique examines all levels of all variables to identify which one best splits the data into the most pure classes (Breiman *et al.* 1984). Wilcoxon sign rank test was used for paired comparisons between infested and uninfested plots.

Results and Discussion

The number of all trees in all plots by diameter class shows the dominance of younger trees indicating abundant undergrowth (Fig. 1). The largest diameters represent single old oak trees, which were sometimes present in mixed stands. Norway spruce trees were concen-

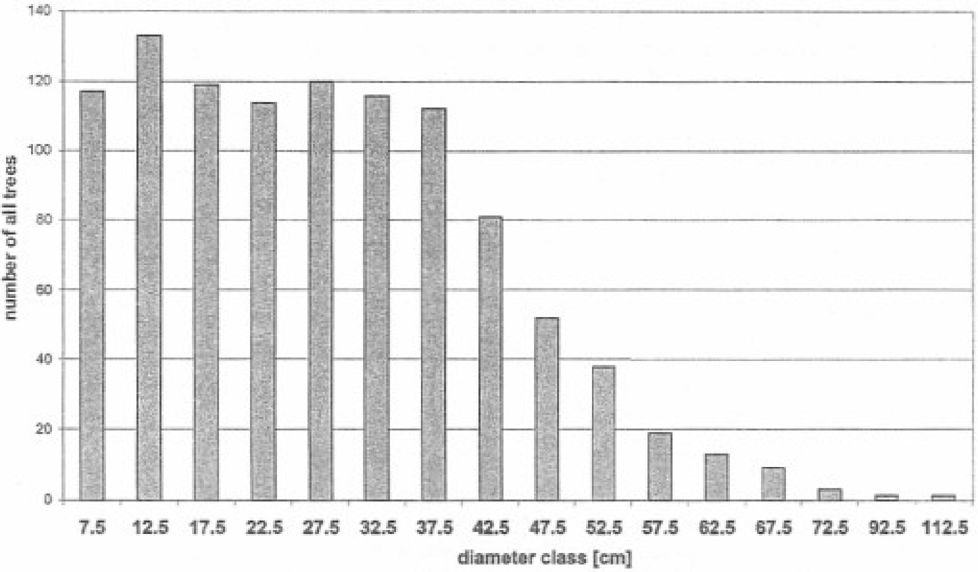

FIG. 1. Number of all trees per 5 cm diameter classes across all plots (diameters indicate midpoint of size)

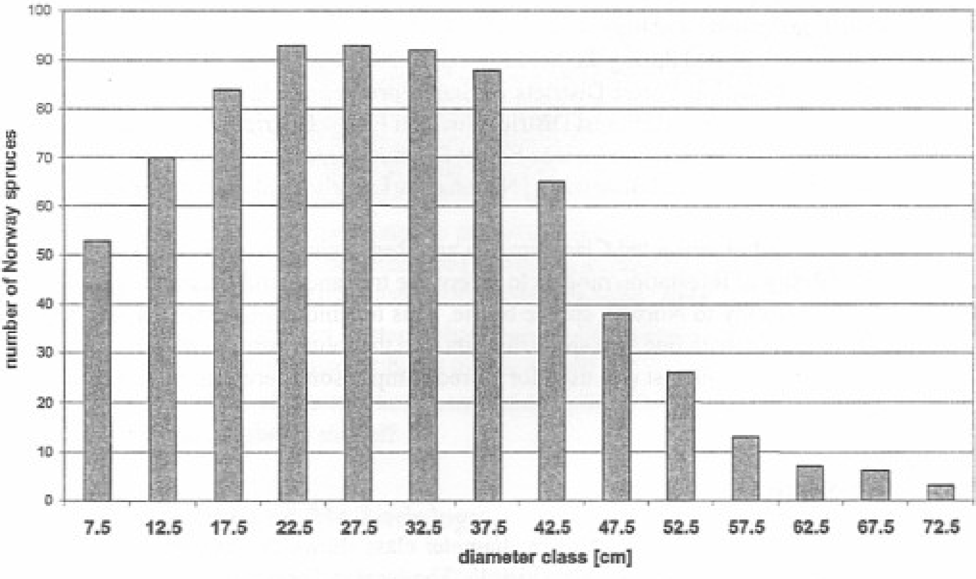

FIG. 2. Number of Norway spruces per 5 cm diameter classes across all plots (diameters indicate midpoint of size)

TABLE 1

Descriptive statistics for all variables measured within all surveyed plots

Variable per plot	N	Range	Minim.	Maxim.	Mean		Std. deviation	Variance
	Stat.	statistic	statistic	statistic	statistic	std. error	statistic	statistic
Sum basal area all spp	200	1.74	0.37	2.12	0.8858	0.0180	0.25521	0.065
Stand density index all spp	200	25.76	6.93	32.69	15.2758	0.2786	3.93970	15.521
Mean dbh cm all spp	200	33.83	16.50	50.33	29.3414	0.4287	6.06209	36.749
Mean height all spp	197	21.55	15.90	37.45	24.4755	0.2848	3.99729	15.978
Spruce mean dbh	200	37.48	16.27	53.75	30.8928	0.5776	8.16815	66.719
Spruce mean height	197	25.05	12.40	37.45	24.5167	0.3511	4.92793	24.285
Sum spruce basal area	200	1.30	0.16	1.46	0.6317	0.0174	0.24551	0.060
Stand density index spruce	200	20.58	3.13	23.72	10.9702	0.2726	3.85452	14.857
Number of trees all spp	200	33	4	37	11.44	0.3300	4.72700	22.348
Qmd all spp	200	32.42	18.73	51.15	32.4540	0.4370	6.18044	38.198
Number of spruce	200	33	2	35	8.06	0.3100	4.44300	19.741
Qmd for spruce	200	40.87	17.22	58.08	33.1052	0.5810	8.21650	67.511
Mean rad growth 91-99	189	3.79	0.36	4.15	1.4869	0.0439	0.60317	0.364
Mean total growth 91-99	189	34.09	3.24	37.33	13.3818	0.3949	5.42851	29.469
Percent basal area spruce	200	83.45	16.55	100	72.3638	1.5337	21.69027	470.468
Mean pgr	189	2.95	0.38	3.33	1.2588	0.0262	0.35987	0.130
Mean height of dom and co-dom spruce	190	28	16.60	44.60	29.2711	0.2863	3.94690	15.578
Valid N (listwise)	184							

Abbreviations used:

Dbh – diameter at breast high, Qmd – quadratic mean diameter, rad – radial, pgr – periodic growth ratio , dom – dominant, co-dom – codominant, spp – species trated in the 22 to 33 cm diameter classes (Fig. 2), which reflect the general age structure of managed Norway spruce stands in Poland.

Table 1 presents a summary of stand conditions observed across all plots sampled. Among measured variables only the number of trees for all tree species per plot registered a significant difference between infested (Table 2) and uninfested plots (Table 3) with higher numbers observed in uninfested plots. Although there is a difference in the number of trees between infested and uninfested sites, the sum basal area for all species was similar in both types of sampled plots.

Studies conducted by Baier (1996) and Negron (1998) indicate reduced growth could be a symptom of reduced tree vigor, which increases susceptibility to bark beetle infestation. Although some decrease of annual radial increment in infested plots was recorded compared to healthy plots (Fig. 3), the differences are statistically not significant.

Forest protection management practices associated with stand density and its effect on spruce beetle behavior have recently been incorporated into forest management assessments in mountain habitats (Netherer et Nopp-Mayr, 2005). No research efforts have been previously conducted to determine the density threshold associated with increased susceptibility to bark beetle attack. The classification tree model (model 1) (Fig. 4) as result from this study indicates increased probability of infestation when stand density index for all tree species in the plot falls below 14.1 (0.02 ha), what could be compare with about 0.6 of stand density according to common density index popular in Polish forestry. Stand density index proposed by Long and Daniel (1990) is easy to obtain because is not dependent on species, height of the tree and quality of the site. Stand density index appears to be a good predictor variable to determine susceptibility. Larger number of trees uninfested plots has a distinct effect on light conditions and lower stand density indexes result in more light and less shaded conditions. Stands with increased light are more susceptible, which is an important variable for spruce bark beetle (Jakuš, 1998).

Previous studies indicate for some bark beetle species that host tree composition affects susceptibility to bark beetle infestation (Schmid et Frye, 1976; Furniss *et al.*, 1979; Netherer et Nopp-Mayr, 2005). As the percentage of spruce increases within a stand, the susceptible tree component is more likely to occur compared to mixed species stands with some species more resistant to windthrow and bark beetle attacks (Jactel *et al.*, 2001).

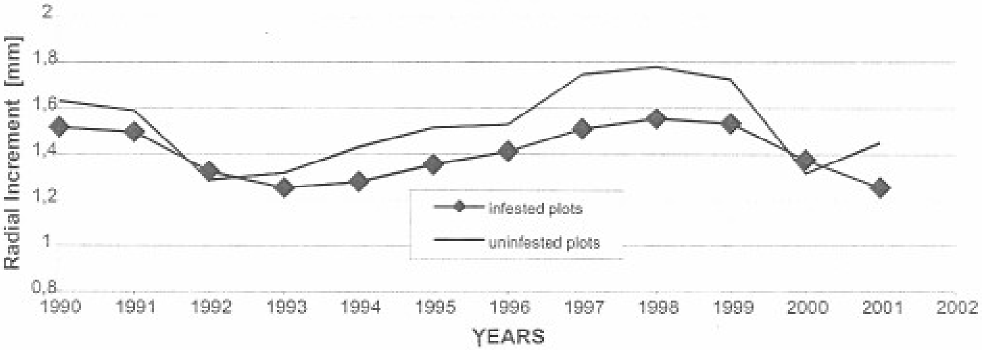

FIG. 3. Average yearly increment of spruce trees on infested and uninfested plots

TABLE 2
Descriptive statistics for infested plots

Variable per plot	N	Range	Minim.	Maxim.	Mean		Std.deviation	Variance
	Stat.	statistic	statistic	statistic	statistic	Std. error	statistic	statistic
Sum basal area all spp	100	1.74	0.37	2.12	0.8595	0.0276	0.27561	0.076
Stand density index all species	100	25.76	6.93	32.69	14.7662	0.4266	4.26562	18.195
Mean dbh cm all spp	100	32.53	17.81	50.33	29.7991	0.6549	6.54907	42.89
Mean height all spp	97	19.83	17.63	37.45	25.1637	0.4629	4.55935	20.788
Spruce mean dbh	100	36.33	17.42	53.75	31.2920	0.7921	7.92076	62.738
Spruce mean height	97	23.05	14.40	37.45	25.2534	0.5138	5.06076	25.611
Sum spruce basal area	100	1.08	0.16	1.23	0.6179	0.0252	0.25216	0.064
Stand density index spruce	100	17.86	3.13	20.99	10.7039	0.4008	4.00768	16.061
Number of trees all spp	100	23	4	27	10.79	0.4300	4.3210	18.673*
Qmd all spp	100	29.36	21.79	51.15	32.8545	0.6539	6.53908	42.760
Number of spruce	100	22	2	24	7.54	0.3700	3.7050	13.726
Qmd for spruce	100	35.54	18.88	54.42	33.3965	0.7855	7.85467	61.696
Mean rad growth 91-99	94	2.72	0.36	3.08	1.4105	0.0536	0.51992	0.270
Mean total growth 91-99	94	24.49	3.24	27.73	12.6946	0.4826	4.67927	21.896
Percent basal area spruce	100	83.45	16.55	100	73.4161	2.2994	22.99394	528.721
Mean pgr	94	2.95	0.38	3.33	1.2283	0.0394	0.38213	0.146
Mean height of dom and co-dom spruce	95	22.60	16.60	39.20	29.5989	0.4017	3.91504	15.328
Valid N(listwise)	90							

* - p<0.05 Wilcoxon test

TABLE 3
Descriptive statistics for uninfested plots

Variable per plot	N	Range	Minim.	Maxim.	Mean		Std.deviation	Variance
	Stat.	statistic	statistic	statistic	statistic	std. error	statistic	statistic
Sum basal area all spp	100	1.16	0.38	1.54	0.9121	0.0231	0.23144	0.054
Stand density index all species	100	19.30	7.05	26.35	15.7854	0.3533	3.53259	12.479
Mean dbh cm all spp	100	28.25	16.50	44.75	28.8836	0.5528	5.52769	30.555
Mean height all spp	100	17.80	15.90	33.70	23.8080	0.3250	3.24993	10.562
Spruce mean dbh	100	37.35	16.27	53.63	30.4936	0.8429	8.42917	71.051
Spruce mean height	100	21.75	12.40	34.15	23.8021	0.4711	4.71124	22.196
Sum spruce basal area	100	1.26	0.19	1.46	0.6454	0.0239	0.23914	0.057
Stand density index spruce	100	19.84	3.88	23.72	11.2365	0.3696	3.69595	13.660
Number of trees all spp	100	32	5	37	12.0900	0.5000	5.03900	25.396*
Qmd all spp	100	30.52	18.73	49.26	32.0536	0.5805	5.80499	33.698
Number of spruce	100	32	3	35	8.5700	0.5000	5.04200	25.419
Qmd for spruce	100	40.87	17.22	58.08	32.8139	0.8593	8.59282	73.837
Mean rad growth 91-99	95	3.64	0.51	4.15	1.5624	0.0687	0.66976	0.449
Mean total growth 91-99	95	32.76	4.57	37.33	14.0617	0.6184	6.02788	36.335
Percent basal area spruce	100	76.07	23.93	100.00	71.3114	2.0365	20.36491	414.730
Mean pgr	95	2.05	0.76	2.81	1.2890	0.0344	0.33568	0.113
Mean height of dom and co-dom spruce	95	24.50	20.10	44.60	28.9432	0.4075	3.97202	15.777
Valid N(listwise)	94							

* - $p<0.05$ Wilcoxon test

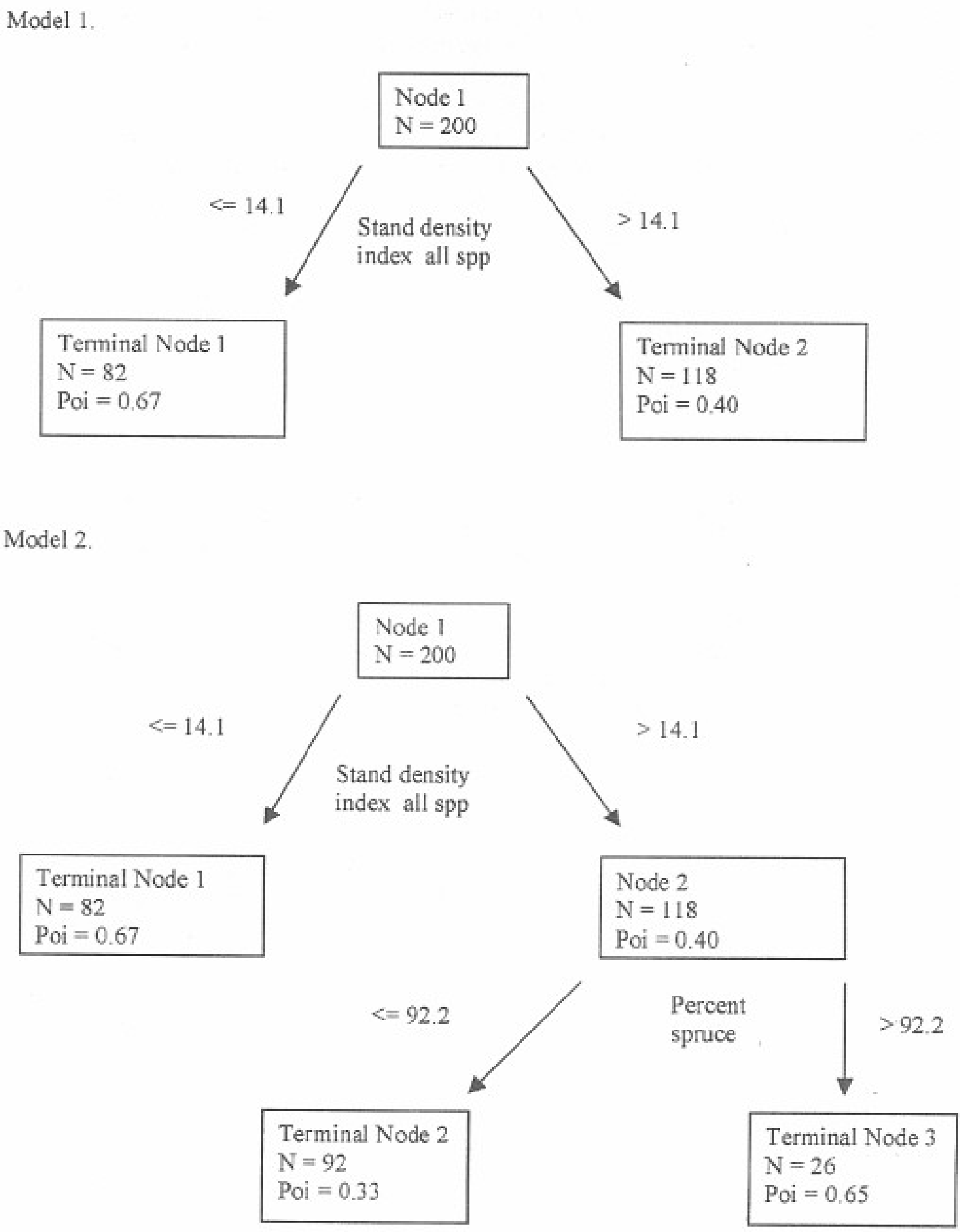

FIG. 4. Classification trees for estimating probability of infestation by the Spruce beetle

Areas infested by *I. typographus* in this study included pure spruce and highly diverse stands. Our analysis indicates that during outbreaks differences in stand susceptibility to bark beetle infestations are not clearly visible between monocultures and mixed stands. This observation is supported by Wermelinger (2004) who concluded that as population pressure from *I. typographus* increases, even vigorous trees in mixed stands are attacked. Although this may be true for outbreak populations of the insect, differences in stand structure and composition may be important mitigating factors affecting Norway spruce beetle activity for building and endemic populations. However, analysis of the data from 0.02 ha plots which were established in sites with a higher spruce composition often occurring in groups, indicates that the percentage of spruce within the plot influenced host susceptibility to spruce bark beetle infestation. Results displayed in classification model 2 indicate stands with increased site density index, characterized by high spruce composition greater than 92.2 percent, had an increased probability of infestation (Fig. 4).

■ Conclusions

Population dynamics of *I. typographus* is highly unpredictable and often influenced by abiotic factors such as extreme weather events like drought or storms. Our results indicate that even during outbreak periods factors such as stand density and spruce percentage are important variables affecting host susceptibility to Norway spruce beetle infestation in northeastern Poland. Similar studies should be conducted in other forested areas to determine if these or other model outputs are appropriate as a Norway spruce beetle susceptibility-rating system in a variety of forested environments.

Stand density and structure affect light conditions within an attacked plot influencing bark beetle behavior. During outbreaks both pure spruce stands and spruce stands with mixed species composition are susceptible to attack by *I. typographus*. However our results show that the proportion of spruce within a stand is an important stand variable influencing susceptibility.

In summary, maintaining higher stand density index and species diversity resulting in multi-structured stands could reduce stand susceptibility to Norway spruce beetle infestation. Stands with these attributes result in reduced light in the understory and a lower percentage of spruce, thus reducing the stands susceptibility to Norway spruce beetle. Forest managers are aware however, that above a particular stand density threshold adverse affects could be encountered such as decreased growth and reduced biomass production.

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Streszczenie (Summary)

Charakterystyka drzewostanu a gradacja kornika drukarza *Ips typographus* (L.) (Col., Curculionidae, Scolytinae) w północno-wschodniej Polsce

W drzewostanach zaatakowanych przez kornika drukarza *Ips typographus* L. zebrano dane dotyczące cech drzewostanu w celu określenia ich potencjalnych powiązań z gradacją kornika. W latach 2001-2002 zebrano dane ze 100 porażonych i 100 nieporażonych (kontrolnych) powierzchni doświadczalnych wielkości 0,02 ha, na terenie 8 nadleśnictw oraz 3 parków narodowych w północno-wschodniej Polsce. Do opracowania modelu prawdopodobieństwa ataku przez kornika drukarza zastosowano technikę CART (Classification And Regression Trees).

Spośród siedemnastu analizowanych wielkości tylko ogólna liczba drzew wszystkich gatunków na powierzchni różniła się istotnie pomiędzy powierzchnią porażoną i kontrolną. Wyniki analizy modeli klasyfikacyjnych wskazują na zwiększone prawdopodobieństwo porażenia przez kornika drukarza powierzchni, w których łączny wskaźnik zadrzewienia dla wszystkich gatunków drzew spada poniżej 14,1 (czyli około 0,6 tradycyjnego współczynnika zadrzewienia) oraz dla powierzchni, gdzie udział świerka jest większy niż 92,2%.

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